

CHEMICAL COMPOSITION OF GYPSY MOTH-KILLED RED OAK

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ABSTRACT

With ultimate salvageability in mind, a study was undertaken to compare the chemical composition of gypsy moth-killed trees to control girdled trees. Groups of red oak (*Quercus* spp.) trees dead 1 through 5 years were harvested, chemically analyzed across three positions vertically in each tree including sapwood and heartwood at each location, and compared to control trees. Significant ($P \leq 0.05$) reductions in sapwood specific gravity occurred for both gypsy moth-killed and control trees. Over 3 to 5 years, sapwood was found to be either missing or showed evidence of advanced wood decay. Calorific values varied across sapwood and heartwood positions of the dead tree age groups but could not be positively correlated with time of tree death. Alkali solubility tests (1% NaOH) showed a progressive increase in extractive yield following tree death, particularly in the sapwood zone. Significant reductions in holocellulose content occurred in the sapwood zone but not in the heartwood. Klason lignin content increased slightly with time following tree death. Wood constituent yields varied and in most cases, no systematic pattern could be established following tree death. No significant differences between gypsy moth-killed and girdled trees occurred. These results support earlier findings in that lumber losses due to biodegradation will occur shortly after tree death.

Keywords: Red oak, gypsy moth, defoliation.

INTRODUCTION

The gypsy moth has defoliated more than 40 million acres in the Northeast since the first major outbreak of this significant forest pest in 1929. In 1981 the moth defoliated more than 5.2 million acres of forestland. In Pennsylvania approximately 2.8 million acres were defoliated, mostly in the oak forest types of the central and eastern parts of the state. Thousands of acres continue to be

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defoliated annually by this insect, and cyclic outbreaks with significant damage to the timber resource will no doubt continue into the future (Fosbroke and Hicks 1987).

A significant aspect of the overall problem from a forest products utilization standpoint deals with salvage of wood from dead, standing red oaks. It is generally accepted that the utility of the dead material will decrease with the increase of time after death of the tree. The salvage value is thus directly related to the application of knowledge relating to the magnitude and rapidity with which changes take place relative to the properties of the wood following death. Even the ultimate salvage utility of the dead trees for firewood will be limited at some point by an excessive loss in caloric value due to advanced deterioration. The physical and chemical analyses reported in this study provide a framework against which to judge the usefulness of progressive degradation of the standing tree for products normally derived from sound trees.

LITERATURE REVIEW

Recently, the utilization of dead hardwoods following defoliation in the oak-hickory forests of the east by insects such as the gypsy moth has been investigated. Studies have been reported on the lumber recovery grade loss and drying studies of gypsy moth-killed red oak as well as the pulp and papermaking properties of gypsy moth-killed trees (Blankenhorn et al. 1980; Garges et al. 1984; Dennis et al. 1986; Baileys et al. 1988; Kessler and Labosky 1988). In addition to these studies, a large body of information has been developed for the time-dependent degradation of the wood properties of coniferous species in the west and south (Levi and Dietrich 1976; Lowery and Hearst 1978; Lieu et al. 1979; Ifju et al. 1979; Kelsey and Shafizadeh 1979; Merrill and Shigo 1979; Koch 1985; Fosbroke and Hicks 1987). The succession and patterns of the invasion of deadwood by insects, bacteria, and fungi are generally known (Nicholas 1973; Kaarik 1974; Gibbs and Gulliver 1977; Lowery and Hearst 1978; Merrill and Shigo 1979; White 1986; Karasevicz 1987). The nature, rate, and magnitude of the progressive and degenerative changes affecting the wood substance in standing dead hardwoods, however, are limited (Karasevicz 1987). Information on these changes would be a valuable aid to those charged with the management of this resource. This study provides additional information required to evaluate the salvage and utilization of the dead timber in a timely manner.

MATERIALS AND METHODS

The red oak group *Quercus* spp. is particularly susceptible to gypsy moth (*Lymantria dispar* (L.)) infestation and subsequent mortality. These studies, therefore, were conducted using members of that group, a common Pennsylvania hardwood timber species.

The sampling method used in this work was designed to follow sequential changes in selected chemical and physical properties of the standing dead trees undergoing biological deterioration. Death of trees that have been defoliated by the gypsy moth is not instantaneous and is actually caused by a combination of biological factors including insects, disease, and physiological stress. A system to stratify sample trees into groups based on the elapsed time that they were standing following defoliation and death was developed. A spectrum of severity of defolia-

tion from light to heavy with subsequent defoliations taking place over several growing seasons may occur. Thus, there is no a priori assurance that a single heavy or a series of light defoliations will result in death of the tree. Since this study deals with the nature, rate, and magnitude of the progressive changes affecting wood quality following death, it was mandatory to establish the time of death. This point was established by girdling both heavily defoliated as well as nondefoliated healthy control trees at the end of the growing season in 1982. The 1982 values reported were obtained from healthy, nondefoliated control trees. All trees divided into defoliated and control groups were harvested annually throughout a 5-year period following initial defoliation and death. Healthy, nondefoliated control trees were harvested at the beginning of the study (1982) to establish baseline chemical, physical, and caloric data.

Three trees were randomly harvested each year (1982 to 1986) within each group from two stands located in Huntington County, Pennsylvania. Within each tree, sample discs approximately 1 in. in thickness were removed at three positions along the vertical axis of the bole: at the base of the butt log, in the middle of the merchantable bole and at a 4 in. diameter top in the crown. Discs were subdivided into heartwood and sapwood (where intact), and composite heartwood-sapwood samples were ground and sieved in preparation for further analysis. It was found that after a period of about 3 years, specifically if the bark of the dead trees had sloughed off, the sapwood was in most instances completely missing. Where the sapwood remained, it was utilized in a composite sample; where absent, the sample was essentially heartwood.

To ascertain the time-dependent changes in the fundamental nature of selected properties of the wood, basic physical and chemical analyses of the degraded wood were evaluated. Analyses, in addition to moisture content, specific gravity, and gross heat of combustion, included solvent extraction, lignin, holocellulose, and ash content and were conducted following TAPPI standards (T 204 os-76, T 222 om-83, Erickson method (1962), and T 211 om-85), respectively. In order to determine quantitative changes in the carbohydrate content of the degraded wood, TAPPI standard T 212 om-183 was followed for alkaline solubility tests. Data were evaluated using a two-way analyses of variance (gypsy moth vs. girdled, sapwood vs. heartwood, control vs. year of tree death) described by Neter et al. (1985). All statistical calculations were accomplished using Minitab (Ryan et al. 1986).

RESULTS

The calorific values of sapwood and heartwood derived from standing dead, red oak trees following defoliation by gypsy moth are summarized in Table 1. Calorific values ranged from 4,570 to 4,626 cal/g for heartwood and from 4,611 to 4,663 cal/g for sapwood over the study period. Statistical differences were measured for both sapwood and heartwood, but no significant reduction in heat value in the time-after-death sequential pattern could be established. With one exception (1982), no statistical differences ($P \leq 0.05$) in calorific values were measured between sapwood (where present) and heartwood within an age group. It should be pointed out, however, that significant reductions in specific gravity occurred in both sapwood and heartwood over the time period examined. This loss in specific gravity would influence the relative heat value of the degraded tree

TABLE 1. *Calorific values (cal/g) of gypsy moth-killed red oak trees.*¹

Year of tree death	Location	
	Heartwood	Sapwood
1982	4,586 Bab ^{2,3}	4,611 Aab
1983	4,626 Ba	4,663 Ba
1984	4,570 a	— ⁴
1985	4,623 Ba	4,627 Aab
1986	4,620 Ba	4,613 Aa

¹ Based on oven-dry samples.² Means with the same capital letter within a row were not significantly different at the 0.05 level of probability.³ Means with the same small letter in a column were not significantly different at the 0.05 level of probability.⁴ Samples were not collected because sapwood was either nonexistent or showed evidence of advanced wood decay.

versus those which are nondegraded, based on total residual weight of the tree. Over the 5-year study period, about a 25% weight loss was observed in the degraded trees due to advanced wood deterioration (Tables 3 and 4).

The alcohol-benzene extractive content and 1% NaOH extractive content for red oak heartwood and sapwood over five growing seasons after death are summarized in Table 2. Alcohol-benzene extractive content varies from 11% to 9% for both gypsy moth defoliated and girdled control trees. In most cases, a slight reduction in yield occurred over time after tree death. An opposite trend was observed in the 1% NaOH extractive yield and, although not statistically significant, a slight increase in alkali extractive content occurred for both sapwood and heartwood over time after tree death increased. Alkali extractive values ranged from a low of 22.6% to a high of 29.6% for controls and gypsy moth defoliated trees. Significantly higher alkali yields were measured in sapwood (gypsy moth defoliated, 27.9%; girdled control, 29.2%) as compared to heartwood (gypsy moth defoliated, 24.6%; girdled control, 26.1%) trees dead for five years.

The average chemical content of red oak sapwood and heartwood five growing seasons after tree death following gypsy moth defoliation or girdling (controls) is summarized in Tables 3 and 4. Average chemical content values were determined from trees in each dead age class and are summarized in Table 5. As would be expected, significant reductions in holocellulose content occurred in sapwood as

TABLE 2. *Alcohol-benzene extractive content¹ and 1% NaOH extractive content² for red oak heartwood and sapwood five growing seasons after death following either gypsy moth defoliation or girdling (controls).*

Tree component	Year of harvest controls					
	1982		1984		1986	
	Alcohol-benzene	1% NaOH	Alcohol-benzene	1% NaOH	Alcohol-benzene	1% NaOH
Heartwood	11.20 Aa ^{3,4}	22.86 Aa	8.87 A	23.95 A	9.37 Aa	24.58 Ab
Sapwood	10.54 Aa	22.74 Ba	— ⁵	—	8.71 Aa	29.59 Aa
Gypsy moth defoliated						
Heartwood	9.63 Aa	23.47 Aa	8.86 A	23.37 A	9.92 Aa	26.07 Ab
Sapwood	8.64 Ab	22.60 Ba	—	—	8.79 Aa	27.88 Aa

¹ Alcohol-benzene extractive content based on the dry weight of unextracted wood.² 1% NaOH extractive content based on the dry weight of alcohol-benzene extracted wood.³ Means within a row followed by the same capital letter among extractive values are not significantly different at the 0.05 level.⁴ Means within a column followed by the same small letter among extractive values are not significantly different at the 0.05 level.⁵ Samples were not collected because sapwood was either nonexistent or showed evidence of advanced wood decay.

TABLE 3. Average chemical content values of red oak sapwood five growing seasons after death following gypsy moth defoliation or girdling (controls).

Chemical content	Year of harvest controls		
	1982	1984	1986
Holocellulose ¹	65.18 Ab ^{2,3}	— ⁴	61.93 Ba
Klason lignin ¹	18.55 Aa	—	19.84 Aa
Ash	0.5333 Aa	—	0.9550 Aa
Specific gravity	0.5100 Aa	—	0.3745 Bb
Gypsy moth defoliated			
Holocellulose ¹	68.22 Aa	—	62.09 Ba
Klason lignin ¹	18.75 Aa	—	20.65 Ba
Ash	0.5356 Aa	—	1.1267 Aa
Specific gravity	0.5200 Aa	—	0.4323 Ba

¹ Chemical content values based on dry weight of alcohol-benzene extracted wood.² Means within a row followed by the same capital letter are not significantly different at the 0.05 level.³ Means within a column followed by the same small letter are not significantly different at the 0.05 level.⁴ Samples were not collected because sapwood was either nonexistent or showed evidence of advanced wood decay.

time after tree death increased; however, no large reductions in holocellulose content were measured in the heartwood zone. In one instance, a higher holocellulose content was measured for dead 5-year girdled control trees. For both gypsy moth defoliated and control trees, holocellulose content ranged from approximately 65 to 67% for heartwood, whereas holocellulose content in sapwood dropped from 68 to 62%.

No statistical differences were measured in klason lignin content for both heartwood and sapwood as time after tree death increased. Klason lignin content ranged from a low of 18.5 to a high of 20.4% for all samples.

Comparisons of the chemical constituents between gypsy moth defoliated and girdled control trees showed inconsistencies in the chemical composition. In some cases statistical differences in constituents were seen, but in others, no differences were observed. For example, statistical differences in the holocellulose content were observed for defoliated and girdled control heartwood trees in 1982. Dif-

TABLE 4. Average chemical content values of red oak heartwood five growing seasons after death following gypsy moth defoliation or girdling (controls).

Chemical content	Year of harvest controls		
	1982	1984	1986
Holocellulose ¹	65.18 Ab ^{2,3}	65.54 Aa	66.04 Aa
Klason lignin ¹	20.37 Aa	19.67 Aa	19.46 Aa
Ash	0.5361 Aa	0.5200 Aa	0.5825 Aa
Specific gravity	0.6826 Aa	0.5720 Bb	0.5220 Ca
Gypsy moth defoliated			
Holocellulose ¹	67.50 Aa	64.15 Aa	64.85 Aa
Klason lignin ¹	18.82 Ab	17.96 Ab	18.48 Aa
Ash	0.5322 Aa	0.5189 Aa	0.7565 Aa
Specific gravity	0.6628 Aa	0.6101 ABa	0.5492 Ba

¹ Chemical content values based on dry weight of alcohol-benzene extracted wood.² Means within a row followed by the same capital letter are not significantly different at the 0.05 level.³ Means within a column followed by the same small letter are not significantly different at the 0.05 level.

TABLE 5. Total tree chemical content values for red oak five growing seasons after death following either gypsy moth defoliation or girdling (controls).

Chemical content	Year of harvest controls		
	1982	1984	1986
Alcohol-benzene extractives	10.87 Aa ²	8.87 Ba	9.04 Ba
Holocellulose ¹	65.41 Ab ³	60.54 Bb	63.98 Aa
Klason lignin ¹	19.46 Aa	19.67 Aa	19.64 Aa
Ash	0.54 Aa	0.52 Aa	0.58 Aa
1% NaOH	22.80 Ba	23.95 Ba	27.09 Aa
Specific gravity	0.6826 Aa	0.5720 Bb	0.4482 Cb
Gypsy moth defoliated			
Alcohol-benzene extractives	9.13 Aa	8.86 Aa	9.49 Aa
Holocellulose ¹	67.06 Aa	64.15 Ba	63.82 Ba
Klason lignin ¹	18.78 Aa	17.96 Ab	19.30 Aa
Ash	0.53 Aa	0.52 Aa	0.90 Aa
1% NaOH	23.04 Ba	23.37 Ba	26.75 Aa
Specific gravity	0.6628 Aa	0.6101 Aa	0.5054 Ba

¹ Chemical content values based on dry weight of alcohol-benzene extracted wood.² Means within a row followed by the same capital letter are not significantly different at the 0.05 level.³ Means within a column followed by the same small letter are not significantly different at the 0.05 level.

ferences in klason lignin content at the same time, however, were not observed. In 1984, differences in holocellulose but not lignin were observed. In 1986, no statistical differences were measured in either constituent. The sapwood holocellulose content, however, exhibited a significant decrease as time elapsed after tree death. Although not statistically significant, a slight increase in sapwood klason lignin content was observed.

These trends were not observed in the heartwood section of the tree. In most instances, only slight changes in both holocellulose and klason lignin content were measured between defoliated and girdled control trees over the study period. In all cases, however, the specific gravity of both sapwood and heartwood decreased as time after tree death increased for both defoliated and girdled control trees. These observations were also observed in the total tree average (Table 5). Statistical differences in alcohol-benzene, holocellulose, and 1% NaOH, but not the klason lignin content, were found to occur as time elapsed after tree death (Table 5).

The within-tree chemical content at the top, middle, and bottom portion of trees dead five growing seasons was evaluated and the data are summarized in Table 6. These results clearly show the variability in the decay patterns within a tree. For example, sapwood specific gravity for the top portion of the tree varied from 0.37 to 0.38 for defoliated and girdled control trees, whereas sapwood specific gravity for the bottom portion of the tree varied from 0.32 to 0.39, respectively, for defoliated and girdled trees. With one exception, alkali-solubility yield was higher for sapwood than heartwood for defoliated and control trees. Klason lignin ranged from a low of 11 to a high of 21%, and holocellulose content ranged from a low of 58 to a high of 66% for all trees. Other than sapwood alkali solubility content, sapwood and heartwood specific gravity values, and sapwood holocellulose content, no clear trends could be established between loss of individual chemical components and time of tree death.

TABLE 6. Chemical content values of the top, middle, and bottom portions of the dead trees for five growing seasons following gypsy moth defoliation or girdling (control).

Chemical content	Controls					
	Top		Middle		Bottom	
	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood	Sapwood
Alcohol-benzene extractives	10.30 Aa ^{2,3}	8.38 Aa	8.81 Aa	7.74 Aa	8.99 Aa	10.02 Aa
Holocellulose ¹	65.13 Aa	63.27 Aa	66.38 Aa	63.80 Aa	66.59 Aa	58.73 Bb
Klason lignin ¹	19.88 Aa	19.78 Aa	18.81 Aa	19.64 Aa	19.68 Aa	20.10 Aa
Ash	0.23 Aa	0.73 Aa	0.15 Aa	0.65 Aa	0.25 Aa	1.34 Aa
1% NaOH	26.24 ABa	29.42 ABb	22.92 Ba	27.95 ABa	24.60 Bb	31.40 Aa
Specific gravity	0.5200 Ab	0.3792 ABa	0.5013 Aa	0.4195 ABb	0.5446 Aa	0.3249 Bb
Gypsy moth defoliated						
Alcohol-benzene extractives	11.51 Aa	9.81 ABa	8.98 ABa	9.02 ABa	9.43 ABa	7.54 Bb
Holocellulose ¹	65.79 Aa	58.48 Ab	64.88 Aa	63.53 Aa	64.12 Aa	64.27 Aa
Klason lignin ¹	18.06 Bb	19.53 ABa	18.27 Ba	21.11 Aa	18.96 ABa	21.33 Aa
Ash	0.24 Aa	0.79 Aa	0.20 Aa	0.80 Aa	1.56 Aa	1.94 Aa
1% NaOH	25.66 Aa	33.38 Aa	22.46 Aa	25.56 Aa	29.10 Aa	24.72 Ab
Specific gravity	0.6349 Aa	0.3704 Ba	0.5230 Aa	0.5331 Aa	0.5045 Ab	0.3915 Ba

¹ Chemical content values based on dry weight of alcohol-benzene extracted wood.

² Means within a row followed by the same capital letter are not significantly different at the 0.05 level.

³ Means within a column followed by the same small letter are not significantly different at the 0.05 level.

RESULTS

The observed variations in the chemical composition of dead standing red oak after tree death could be attributed to progressive but highly variable wood degradation, which in turn depends on several factors (Rowell 1983; Koch 1985; Karasevicz 1987). The type of fungi that invade dead standing oak will play a major role in uneven deterioration since each fungus inherently decays wood at variable rates. Other factors such as stand density, aspects that affect wood species composition, climatic conditions, and wood moisture would all play important roles in the extent and rapidity of wood deterioration (Rowell 1983; Koch 1985; Karasevicz 1987). Earlier utilization studies of dead oaks indicated that when bark remains intact on the bole following tree death, sufficient moisture is present to promote decay even 5 years after tree death (Karasevicz 1987; Kessler and Labosky 1988).

Karasevicz (1987) determined the types of deterioration and rate of degradation in trees following gypsy moth defoliation. She found wood of girdled control trees deteriorated faster than that of biologically killed trees. Similar observations were made in this study in that statistically ($P \leq 0.05$) lower specific gravities were measured for girdled control trees compared to gypsy moth-killed trees dead for two and five years (Table 5).

The type of fungi that invades dead oak affects the residual chemical components in dead wood. White-rots are known to decompose cellulose, hemicellulose, and lignin at approximately the same relative rates and brown-rots primarily attack cellulose (Rowell 1983; Koch 1985). Karasevicz (1987) identified the successional pattern of fungi invasion in gypsy moth defoliated oaks to be the staining organisms, followed by white- and brown-rots. Considering the successional pattern of fungal invasion and the varying mode and extent of degradation by many invading fungi, it is understandable why significant reductions in holocellulose content occurred for trees dead up to 5 years, particularly for wood in the sapwood zone. In this study, specific gravity reductions in the sapwood zone were rather drastic 3 years following death, whereas heartwood specific gravities changed at a much slower rate.

The klason lignin content of girdled controls and gypsy moth-killed trees did not change as dramatically as did the holocellulose content and 1% alkali solubility. The klason lignin content increased slightly in the sapwood zone as time after tree death increased. Relatively constant lignin values were observed, however, in the heartwood zone. In two instances, significantly higher klason lignin contents were measured in girdled control trees compared to gypsy moth defoliated trees. Based on earlier reports, it appeared that the invading white-rots were prevalent shortly after tree death and these observations support those reported by Karasevicz (1987). As expected, as time after tree death increased, significantly higher ($P \leq 0.05$) alkali extractables were obtained. This indicated that the carbohydrate portion of the tree was readily extracted, as evidenced by the loss in holocellulose content.

Earlier pulping studies with gypsy moth-killed oaks indicated that variations in total pulp yields occurred with time after tree death (Kessler and Labosky 1988). The white-rot fungi left behind holocellulose rich wood, which was later utilized by brown-rots (Table 5). A significantly higher holocellulose content was measured for gypsy moth defoliated oak dead 1 year compared to trees dead for 3 and 5

years. Similar trends were also observed for girdled control trees; the reductions in holocellulose content, however, were erratic. The chemical composition of dead trees observed in this study supports an earlier study where it was found in some cases that higher pulp yields were obtained from dead trees compared to live control trees (Kessler and Labosky 1988).

The calorific values of degraded wood, coupled with the degradation rates of both brown-rot and white-rot fungi, did not produce a systematic pattern of heat loss with time after tree death. Although specific gravity changes varied by as much as 25% and the chemical components varied, in only two instances were statistical differences in calorific values observed to occur between dead age groups (Table 1). A higher heating value for hardwoods was reported to occur for extractive-free wood as klason lignin content increased (White 1986). This was not observed in this study, although a slight increase in klason lignin was measured for gypsy moth defoliated trees (Table 5). The data clearly indicated no systematic pattern of combustive heat loss with time after tree death. Similar conclusions were drawn by Blankenhorn and coworkers (1980) who found the gross heat of combustion value in relation to mass loss for fungally degraded aspen (white-rot and brown-rot) to be insignificant compared to nondegraded aspen wood.

CONCLUSIONS

Over this 5-year study, significant reductions in wood specific gravity occurred in both gypsy moth defoliated and girdled control trees, with sapwood degrading at a faster rate than heartwood. Caloric values of residual wood did not decrease in a sequential manner as time elapsed after tree death. Nonetheless, over this period a 25% loss in tree mass had occurred. In some cases all the sapwood was biodegraded and lost to decay. Significant reductions in the holocellulose and an increase in alkali solubility contents occurred in the sapwood as time after tree death increased. No statistical differences in the klason lignin and holocellulose contents were found in the heartwood zone as time after death increased. The klason lignin content remained unchanged over the 5-year degradation period for girdled control trees. In most cases, lower klason lignin contents were found in gypsy moth defoliated trees than in the girdled control trees.

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